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THE APPLICATION OF REMOTE SENSING TO THE DEVELOPMENT

AND FORMULATION OF HYDROLOGIC PLANNING MODELS

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EXECUTIVE SUMMARY

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I. INTRODUCTION

The launch of LANDSAT has for the first time provided the water
resource manager and practical hydrologist with broad prospects for ef-
ficient acquisition of essentially real-time data. These are usable for
hydrologic land use assessment, surface water inventory, and for the ex-
traction of information pertinent to soil properties. This information
has value not only by and in itself, but also to construct the watershed
transfer function for hydrologic planning models aimed at estimating peak
outflow from rainfall inputs.

The reduction of satellite data to practical, operational information
requires a clear, easily applicable methodology for converting these data
into quantitative hydrologic parameters.

The fundamental objective of this effort is the development of
such a methodology and its transfer to hydrologic users. It was realized
that such technology transfer could be made far more effective by the parallel
development and eventual demonstration of the results of a model, specifi-
cally structured to take full advantage of the capability of LANDSAT - for
example, its frequent recurrence and consequent ability to determine
seasonal variations in the watershed's conditions. The category of
planning models was chosen for development and demonstration because of
its great practical importance in the design of waterworks, because of
the wide diffusion of such models down to capillary levels within the
hierarchy of water resources users, and because their implementation is

relatively simpler than management models, thus making optimum use of the resources available for this effort.

Consequently, the effort was structured along two major routes: the development of a hydrologic planning model specifically based upon remotely sensed inputs, including its test and verification from existing records; and the application of LANDSAT data to supplying the model's quantitative parameters and coefficients. Included was the investigation of the use of LANDSAT data as information inputs to all categories of hydrologic models requiring quantitative surface parameters for their effective functioning.

The effort thus far has consisted of three phases. The first focused on the definition of the "drivers" - those hydrologic processes to which peak runoff is most sensitive - and upon the synthesis of a simple yet effective model for the estimation of long-recurrence outflows. The results of the first phase effort were presented in the Final Report, "The Application of Remote Sensing to the Development and Formulation of Hydrologic Planning Models," dated January, 1975. The second phase extended this work to include the development of a routing model for use in sensitivity analyses, and a quantitative investigation of the accuracy and completeness of the hydrologic information which can be extracted from remotely-sensed imagery.

These findings were reported in the January, 1976, Final Report. The current phase has concentrated on validation of the model and upon the synthesis of a simple methodology for performing hydrologic analyses from LANDSAT imagery.

II. APPROACH TO THE PRESENT EFFORT

The current phase of this effort brought the prior work to a conclusion through four tasks:

Task 1   The complete development of the routing model.

Task 2   The derivation of hydrologic parameters from LANDSAT imagery for an additional watershed, making a total of five for which such analysis has been performed.

Task 3   The documentation of procedures for extracting hydrologic information from LANDSAT imagery.

Task 4   Demonstration of the procedures and model to a selected group of users.
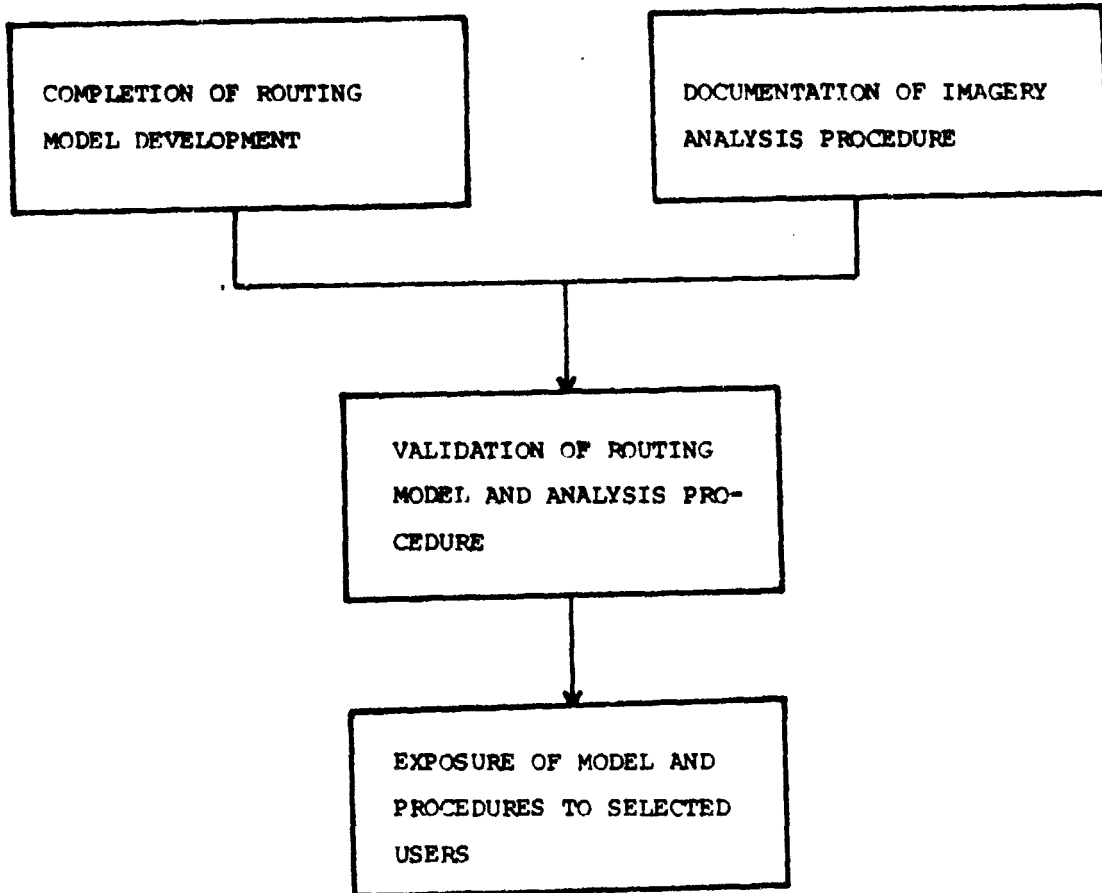
Figure 1 is a flow chart showing the objectives set out for this phase.

Task 1 constituted the synthesis of a routing module for the planning model. This has been completed and programmed in FORTRAN IV for operation on small-capacity digital computers. The model features user-interactive operation and amenability to present and potential inputs from satellite remote sensors. Task 1 culminated in the simulation of a peak runoff event as taken from actual gage records.

Task 2 involved the hydrologic land use classification of the Bucklodge Branch watershed in Montgomery County, Maryland. The techniques developed for Task 3 (described below) were applied to cover classification of Bucklodge Branch. This task also included the derivation of model parameters from the remotely sensed information.

Task 3 resulted in the development of generalized procedures for extraction of quantitative information from LANDSAT imagery through simple visual analyses. The findings showed that relatively uncomplicated techniques

FIGURE 1: FLOW CHART OF CURRENT PHASE

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┌──────────────────────────┐        ┌──────────────────────────┐
│  COMPLETION OF ROUTING   │        │  DOCUMENTATION OF IMAGERY │
│  MODEL DEVELOPMENT       │        │  ANALYSIS PROCEDURE       │
└──────────────────────────┘        └──────────────────────────┘
              │                                    │
              └─────────────────┬──────────────────┘
                                ▼
                  ┌──────────────────────────┐
                  │  VALIDATION OF ROUTING   │
                  │  MODEL AND ANALYSIS PRO- │
                  │  CEDURE                  │
                  └──────────────────────────┘
                                │
                                ▼
                  ┌──────────────────────────┐
                  │  EXPOSURE OF MODEL AND   │
                  │  PROCEDURES TO SELECTED  │
                  │  USERS                   │
                  └──────────────────────────┘
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can yield results adequate for hydrologic modelling.

The final task included identification of prospective user groups and exposure of the model and associated analysis procedures to them.

III. PROCEDURES FOR EXTRACTION OF HYDROLOGIC DATA FROM LANDSAT IMAGERY

The fraction of rainfall which eventually becomes stream discharge depends in large measure upon the character and condition of the land surface over which it flows. Rain falling on a watershed is subjected to the retardant forces of the surface cover; this retardation, in turn, regulates the proportions of the water which run overland, infiltrate or are evaporated. A rural watershed covered with thick grass and trees, for example, will have a much different response to a peak rain event than will its urbanized counterpart.

Prior work in remote sensing for hydrology has shown that surface cover can be derived from presently available LANDSAT imagery. A problem with reducing potential to practice, however, has been the absence of standard procedures for extraction of required data by uncomplicated, inexpensive, yet accurate, means.

One objective of this effort was the development of procedures for utilizing LANDSAT data to determine watershed surface cover. An important result is that the procedure eventually developed is applicable not only to the specific model developed herein, but can be generalized to all hydrologic models.

The resolution of land cover detail required by the models varies, but is generally consistent with the current capabilities of LANDSAT sensors. The exceptions are those models designed to analyze intra-urban hydrology; satellite data will be of limited applicability here. For those models suited to evaluation of larger watersheds, most requirements can be met through a Level I land use classification, which can be accomplished from remotely sensed data.

III.1 Alternative Techniques for Analysis of LANDSAT Imagery

Because LANDSAT data is produced in two forms, computer compatible tapes (CCT's) and "photographic" images, two options for its analysis exist - computer and visual classification/mensuration. The first involves the development of mathematical/statistical algorithms for separation of themes based upon the relative output of each of the sensors. Visual analysis is the same with the exception that the algorithm is mental. The interpreter segregates on the basis of the individual or summed reflectance levels of the multispectral sensor bands. ECOSYSTEMS work in hydrology and other application areas, has made obvious a number of factors making visual analysis preferable for "complex" scenes and low-cost applications. Principal among these are:

1. Minimization of Training Sample Requirements
2. Maximum exploitation of Multi-Temporal Properties of LANDSAT Imagery
3. Optimization of Ground Truth
4. Accuracy of Results
5. Equipment Requirements/Costs

Even with simple visual means two problems still constitute impediments to the practical use of LANDSAT imagery: 1) the unavailability of projection/analysis devices amenable to complete analysis of satellite imagery at low cost; 2) the lack of a standard procedure. ECOsystems' effort has resulted in techniques for solving both these problems.

A device for easy analysis was developed and tested which is suited to LANDSAT scales and resolutions.

The following describes a recommended procedure for deriving quantitative hydrologic data from the MSS imagery.

III.2 VISUAL EXTRACTION OF HYDROLOGIC LAND USE FROM LANDSAT IMAGERY

The utility of LANDSAT imagery can be augmented by combining the individual bands into composites. The addition of color to each band facilitates the separation of surface themes, because it allows the analyst to see the information contained in all bands simultaneously.

A simple, low cost procedure for color-encoding individual black and white images and compositing them is available in the diazo process. Its best usage, as developed by ECOSYSTEMS, is to produce plastic transparencies in shades of a single color directly from LANDSAT 9" x 9" images. The procedure is repeated for each band, producing it in a different color. Finally, the diazo transparencies are overlayed, registered, and glued together to form a composite image.

The visual analysis of diazo composite imagery for hydrologic land use proceeds in six steps:

1) Preparation of "tuned" Diazo Composites
2) Image Projection/Ground Truth Overlay
3) Watershed Delineation
4) Analysis of Ground Truth
5) Segregation of Surface-Cover Themes
6) Quantification of Hydrologic Parameters

III.2.1 Preparation of "Tuned" Diazo Composites

No single LANDSAT band contains all the hydrologic information; each channel derives the reflectance of the surface in a different spectral range. Full advantage of reflectance differences has generally not been exploited in visual analysis; rather, past work has relied mostly upon LANDSAT's geometric properties - identification of shape and form

from single color composites.

The diazo compositing process affords the analyst the opportunity to optimize the value of radiometric differences.

By combining both positive and negative images, and by developing the diazo film to suppress undesireable features, the resultant composite can be "tuned" to accent particular surface cover classes.

III.2.2 Image Projection

Land use classification to Level 1-2 requires significant magnification of the 1:1,000,000 scale LANDSAT imagery. This has previously been a drawback of visual analysis hardware - devices which could permit enlargement to greater than about 10X have been very expensive. The cost can be greatly reduced, however, as exemplified by the imaging system developed for such analysis by ECOSYSTEMS. Experience with this system has shown that magnifications of about 40X are convenient for land cover analysis, since they permit the direct overlaying of 1:1,000,000 LANDSAT images upon USGS 1:24,000 topographic maps. To insure the color-fastness of the images during analyses, color slides for projection should be made from the diazo composite.

III.2.3 Watershed Delineation/Ground Truth Overlay

Analysis of hydrologic land cover begins with the demarcation of the boundaries of the watershed. Except in regions of very high relief, some ancillary information is generally required. This is readily available in the form of USGS topographic maps. Stereo aerial photographs, where available, can also be used. The watershed ridge line is first

traced on the map. The LANDSAT image is projected over the map and aligned using roads, rivers, lakes, or other prominent features for reference. A sheet of tracing paper is placed over both and the ridge line drawn on it. The map is then removed.

III.2.4 Analysis of Ground Truth

There are a number of widely-available sources of ground truth which can be valuable aids to the interpretation of satellite imagery. Among these are:

1) topographic maps (USGS)

2) soil surveys (SCS)

3) aerial photographs

Prior to evaluation of the LANDSAT images, all available ground truth should be collected. The data obtained should be summed into a base map for the basin. All surface features discernible from the ground truth should be designated on the map. In the ideal case, ground truth is sufficiently complete to designate a gross, even though mostly outdated, land use map for the entire basin; the function of the LANDSAT data, in this case, is to update the older information and to provide the important seasonal information which it lacks.

III.2.5 Classification of LANDSAT Themes

The next step in surface cover analysis is the actual classification of themes from the diazo composite. The image has been projected on the work surface and the watershed boundaries established. The analyst must then determine how many separable themes, or colors, exist within the scene. The analyst compiles a tracing of the themes which are

identifiable. Once drawn, it is helpful to assign an identifier to each area delineated and identified. This insures repeatability and also facilitates validation by other interpreters.

III.2.6 Quantification of Hydrologic Parameters

With the land use map in hand, the derivation of model parameters can proceed as it would using any source of surface cover data. The exact procedure will vary with the model used; most, however, require only that an "average" surface cover be derived. This can be computed directly from the map.

IV. DEVELOPMENT OF REMOTE SENSING MODEL AND APPLICATION TO TEST WATERSHED

During the course of this project, several criteria for planning

models using remote sensing were developed. They include:

1) The model should consider all hydrologic "drivers," i.e.,
    the surface and sub-surface processes which significantly
    affect the discharge peak rate and duration.

2) It should take maximum advantage of presently feasible
    remote sensing inputs (surface cover) and be amenable
    to new ones (soils, soil moisture, etc.) as they are
    developed.

3) A principal function of the study should be to demonstrate
    to prospective users of LANDSAT data how remote sensing
    techniques can be applied to the general class of planning
    models with actual watershed data.

A model has been deduced from standard practice and modified to a

form consistent with these criteria. It simulates the flow of rainwater

over the surface of a watershed, subjects it to subsurface abstraction

(using the Holtan infiltration formula); and routes the excess through

stream channels to the outlet. Surface cover, land use, soil type, soil

moisture content, basin and channel physiography and topography are

explicitly considered.

As presently configured, the model consists of an overland flow

and a channel flow module. The model was tested against gage records

for the Bucklodge Branch watershed in Montgomery County, Maryland.

Surface parameters for the model were derived directly from LANDSAT

imagery using the techniques described above.

Results of the overland and routing runs are shown in Figure 2.

The model exhibited a good approximation of actual discharge as computed

FIGURE 2

RAINFALL/RUNOFF EVENT OF 12 - 17 JUNE 1974

BUCKLODGE BRANCH WATERSHED
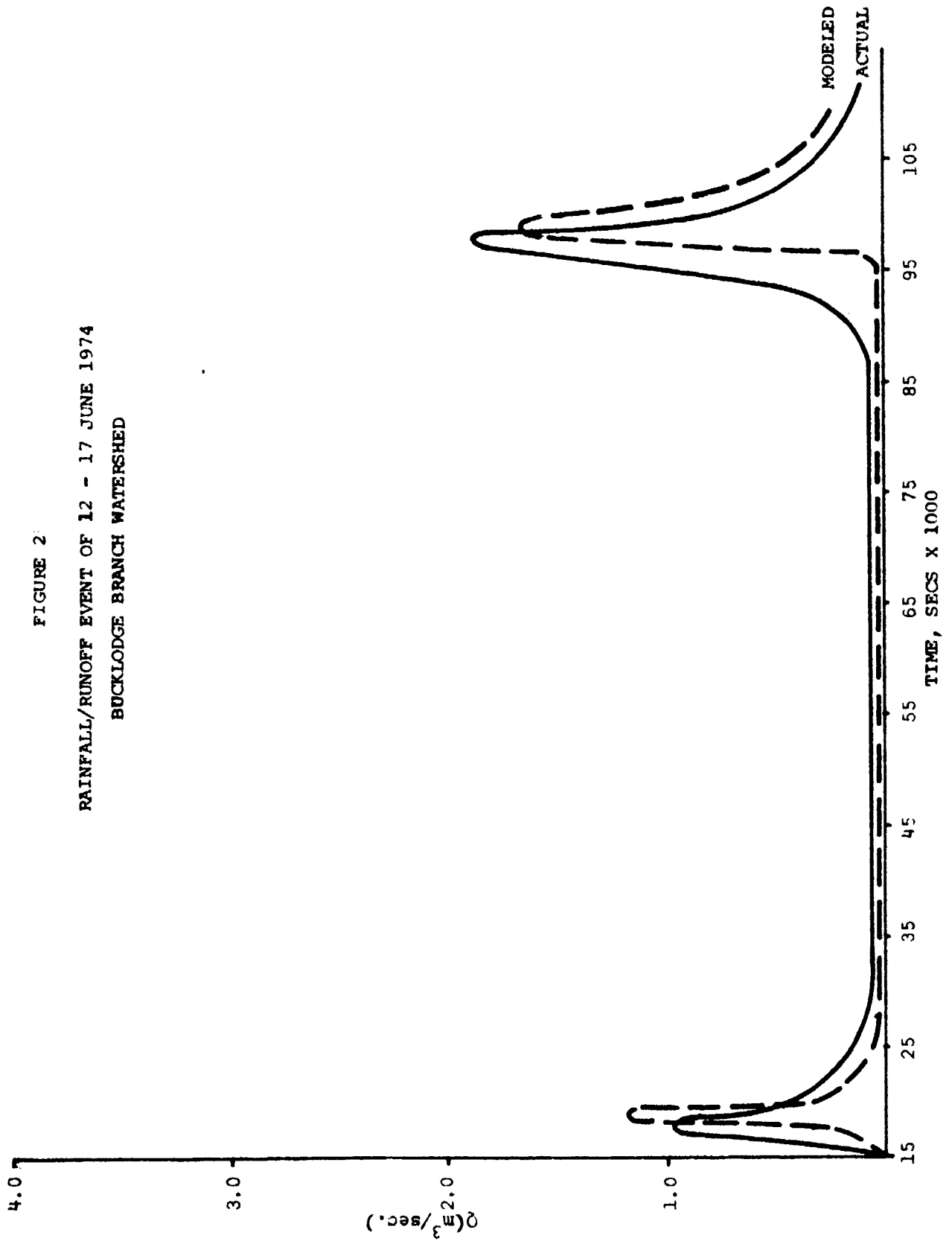
from the gage records and rating curve. The results to date are encouraging.
Even more important from the standpoint of modeling, however, is that the
analysis techniques developed have been successfully related to actual
hydrologic situations. This applicability extends beyond the model
developed in this effort, and should prove valuable to a large class of
modelers and users within the hydrologic community.

V. SUMMARY OF USER CONTACTS MADE TO DATE

Efforts made during this study to foster the expanded use of remote
sensing for hydrologic modeling encountered the impediments inherent in
any new research effort. Nevertheless, significant successes were en-
countered with overseas users. Principal among these were:

1. A hydrologic modeling effort, based essentially upon the
    developments accomplished under NASA sponsorship, was
    contracted by the Region of Tuscany, Italy.

    The model embraces a watershed of approximately 90,000
    hectares, with mixed urban, agricultural, forest,
    mountainous contents. The model must be able to:

    a) Predict runoff events in real time for
        matching supply against demand.

    b) Provide flood warning.

    c) Provide accurate runoff predictions for
        unusual events (planning model) for the
        sizing of waterworks.

    d) Simulate the effect of changes in land use--
        reforestations, industrial parks, urban ex-
        pansion--upon the watershed's hydrologic re-
        gime.

    The effort additionally includes complete transfer of
    modeling and remote sensing technology to the customer.
    This effort proved that the technique of planning models
    developed herein could be extended to general hydrologic
    modeling. The Tuscany model includes quarterly updates
    of the ground cover of the entire watershed from LANDSAT-
    derived information.

2. The specification of a facility for the analysis of LANDSAT
    data was contracted by the same customer. This includes

visual and computerized data processing, employing their on-premise 370/135 computer, and using the LANDSAT data derived from the Telespazio receiving station located near Rome, Italy. The LANDSAT data are to be used for general land-use information as well as for hydrologic modeling.

3. An image-analysis device, of the type described previously, was acquired by the University of Naples, Italy, for the analysis of land use, water pollution and the inventory of selected crops.

4. A land-use map of high precision, including hydrologic pro-perties, was contracted by the Region of Basilicata, Italy. The techniques employed will be those developed under this effort and reported herein.

The high interest of the foreign user community is attributed to the relatively small number of agencies working in hydrologic modeling and the concentration of these activities within regional governmental users.

The domestic situation differs in that the level of the technology transfer effort required is proportional to the number of users involved. On the domestic scene, initial contacts have been made to date with U.S.G.S., Water Resources Division, USDA, Agricultural Research Service, and the Maryland Department of State Planning. As previously discussed, cultivation of interest with these and other organizations will be greatly aided by concise benchmark tests.

VI. SUMMARY OF RESULTS AND CONCLUSIONS

The objectives of the current effort have been to complete and test a hydrologic planning model making maximum use of remotely-sensed inputs; to document procedures for extraction of pertinent parameters from satellite data; and to expose the model and techniques to prospective users.

In the course of this investigation, several findings and conclusions have been reached and are described below:

The Importance of Surface Parameters to Hydrologic Models

The surface-related parameters used by existing hydrologic models (Manning's "n," S.C.S. Curve Number, etc.) can be derived from LANDSAT imagery to the required accuracy. The opportunity is available to take advantage of the radiometric and multi-temporal properties of the data to facilitate identification and classification. Moreover, potentials exist for remote monitoring of soil and soil moisture which would be of great value to hydrologists.

Planning Model Development

A simple model which is amenable to remote sensing inputs has been developed and tested; it exploits LANDSAT data for surface cover input and can accept soil moisture information as this becomes possible. The test was performed for the Bucklodge Branch, Maryland, watershed. Accuracy achieved to data appears commensurate with those of conventional models. The principal purpose envisioned for the model and benchmark test is to demonstrate to prospective users that satisfactory results can be achieved and to show how similar analysis procedures might be

applied to their watershed with their models.

Synthesis of Analytic Procedures

Our experience has shown that a significant share of hydrologic modeling is being performed under the auspices of local governments. Consequently, two impediments to the use of satellite data arise. First, there is a lack of standard procedures for extraction of hydrologic data. Second, the expense involved with current computer/optical practices is a deterrent to use. This report proposes a procedure for simple visual analysis of LANDSAT images which is accurate enough for use in conjunction with hydrologic models. It has been determined further that these techniques extend beyond the field of hydrology and can have equal applicability to agriculture, land use, etc., analyses.

Contacts with Prospective Users

To date, contacts have been made with both foreign and domestic users. Due to the relatively new state of modeling overseas, the response has been greater there. One Italian region has embarked on the analysis of a major watershed, spawned in part by this investigation. Other regions have expressed interest. Domestic acceptance will be fostered by the demonstration of concise procedures and satisfactory results. Such a purpose is intended for this document.